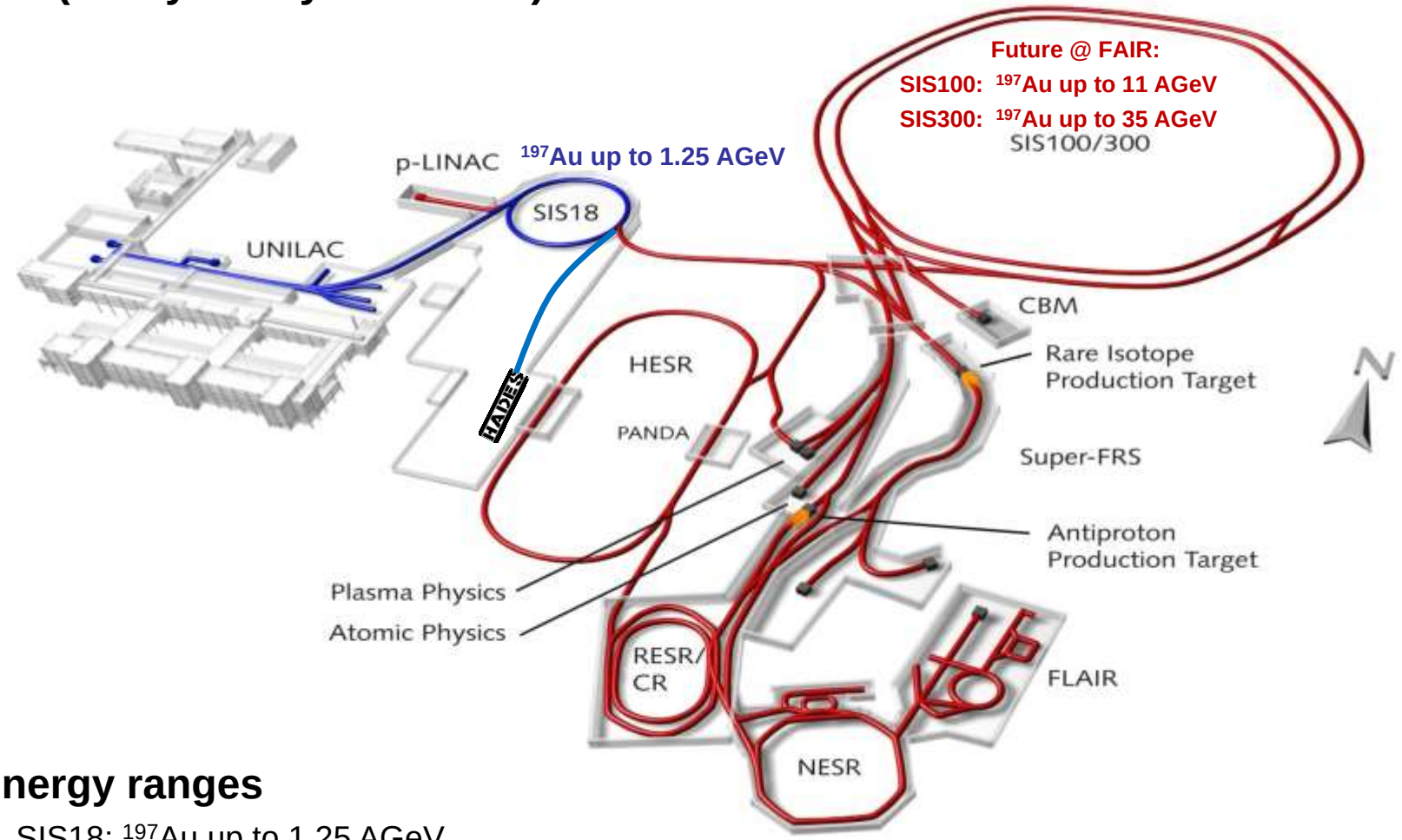
HADES at FAIR

- **Introduction**
  - The HADES Spectrometer – overview
  - Nuclear matter at SIS18 and SIS100/300
- **HADES performance – SIS18**
  - Dielectron probes
  - Strangeness production
  - Pion induced reactions
  - Benchmark test for FAIR: Au + Au @ 1.23 AGeV
- **HADES performance study – FAIR**

Jerzy Pietraszko, GSI Darmstadt
for the HADES Collaboration

SIS18 and FAIR (SIS100 and SIS300)

SIS (heavy-ion synchrotron) at GSI Darmstadt

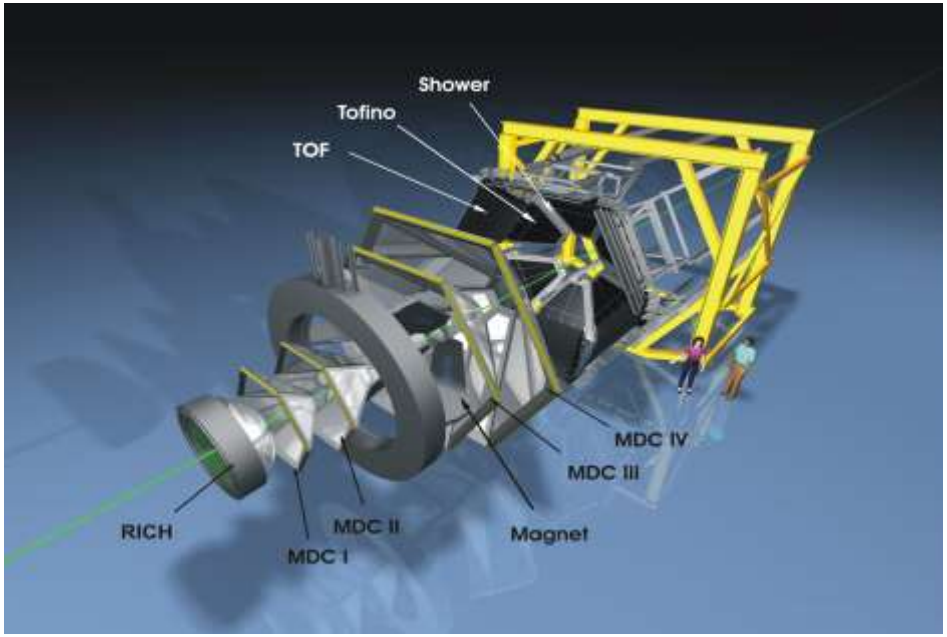


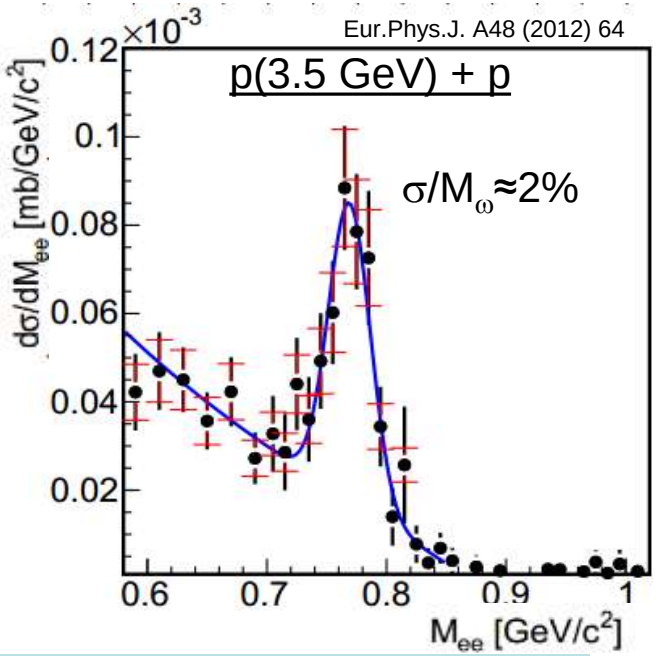
Energy ranges

- SIS18: ^{197}Au up to 1.25 AGeV
- SIS100: ^{197}Au up to 11 AGeV - future HADES/CBM
- SIS300: ^{197}Au up to 35 AGeV - future CBM

Experimental apparatus: HADES

(The High-Acceptance Di-Electron Spectrometer)



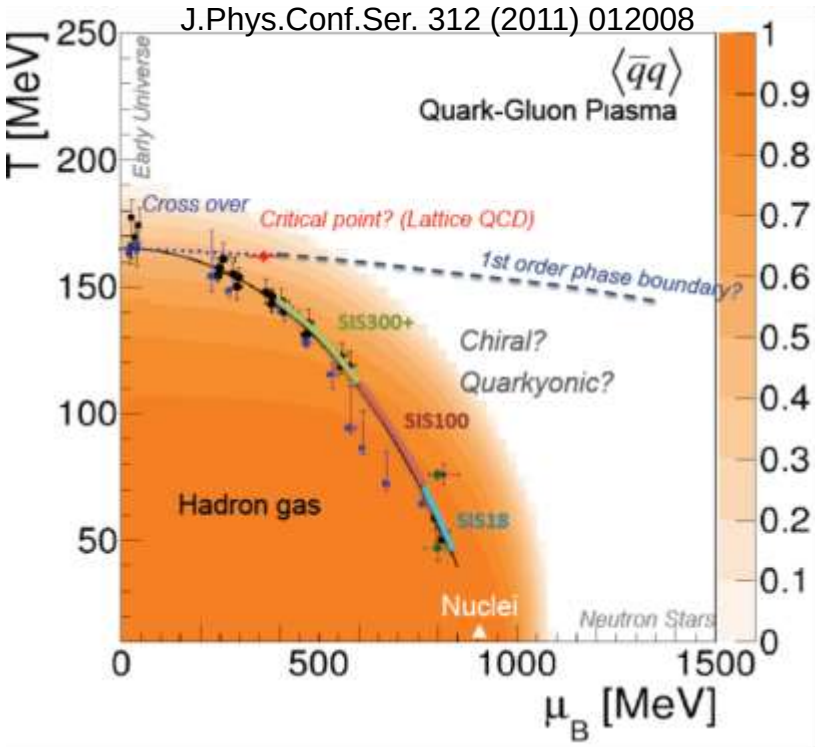


- ✓ Geometrical acceptance: 2π in φ; $18^0 < \theta < 85^0$
- ✓ Di-electron pair acceptance ≈ 35 % (VM→e+e-)
- ✓ Low mass spectrometer
  - RICH: $x/X_0 < 1\%$
  - MDC: $x/X_0 \approx 0.42\%$
- ✓ $\sigma/M_\omega \cong 2.0\%$

Strategy: Systematic di-electron and multi-strangeness measurements in heavy ion, proton and pion induced reactions. K, ρ, ω, φ, Λ, Ξ etc. particles produced sub-threshold.

Beams from SIS18 and SIS100 at FAIR.

Nuclear matter at SIS



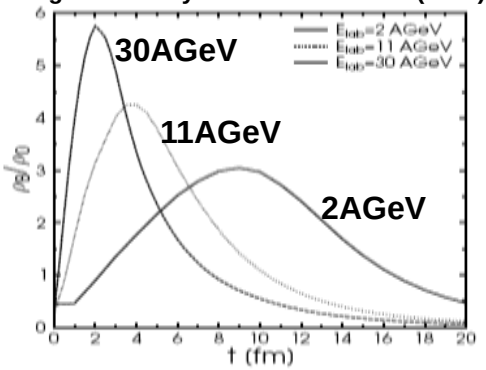
SIS 18 on the phase diagram

- Large μ_B and moderate T
- Densities: $\rho_{max}/\rho_0 \cong 2 - 3$; T $\cong$ 50 -100 MeV

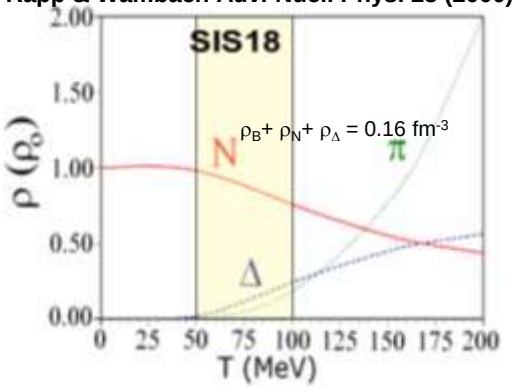
Phase diagram:
McLerran L and Pisarski R D 2007 Nucl. Phys. A 796 83
McLerran L, Sasaki Ch and Redlich K 2009 Nucl. Phys. A 824 86
Stat. model:
Cleymans J and Redlich K 1999 Phys. Rev. C 60 054908

Nuclear matter at SIS

S. Vogel et al.Phys. Rev. C78 044909 (2008)



Rapp & Wambach Adv. Nucl. Phys. 25 (2000)



- Large μ_B and moderate T
- Densities: $\rho_{max}/\rho_0 \cong 2 - 3$; $T \cong 50$ -100 MeV
- Matter dominated by baryonic resonances (~30%),

  $N_\pi/A_{part} \approx 10\%$
- $\tau_{system} \cong 10 \cdot \tau_{resonance}$ →long lifetime of the nuclear fireball

  → multistep processes, dominant role of resonances

Energy ranges at GSI (existing and future):

- SIS18: ^{197}Au up to 1.25 AGeV
- SIS100: ^{197}Au up to 11 AGeV - HADES/CBM
- SIS300: ^{197}Au up to 35 AGeV - CBM

Probe - dielectron decays of VM

Meson	Mass (MeV/c^2)	Γ (MeV/c^2)	$c\tau$ (fm)	Main decay	e^+e^- BR
ρ	768	152	1.3	$\pi^+\pi^-$	4.4×10^{-5}
ω	782	8.43	23.4	$\pi^+\pi^-\pi^0$	7.2×10^{-5}
ϕ	1019	4.43	44.4	K^+K^-	3.1×10^{-4}

Ideal probes for medium effects (Vector Mesons):

Short life time

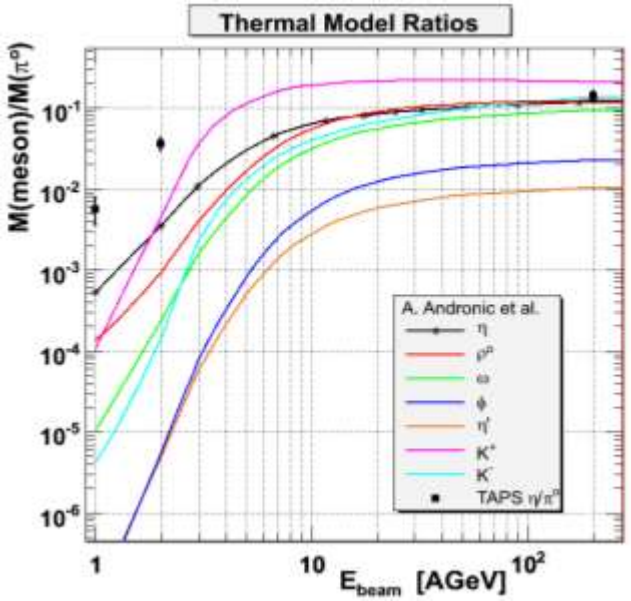
- Decay inside hadronic medium

Decay channel into lepton pairs

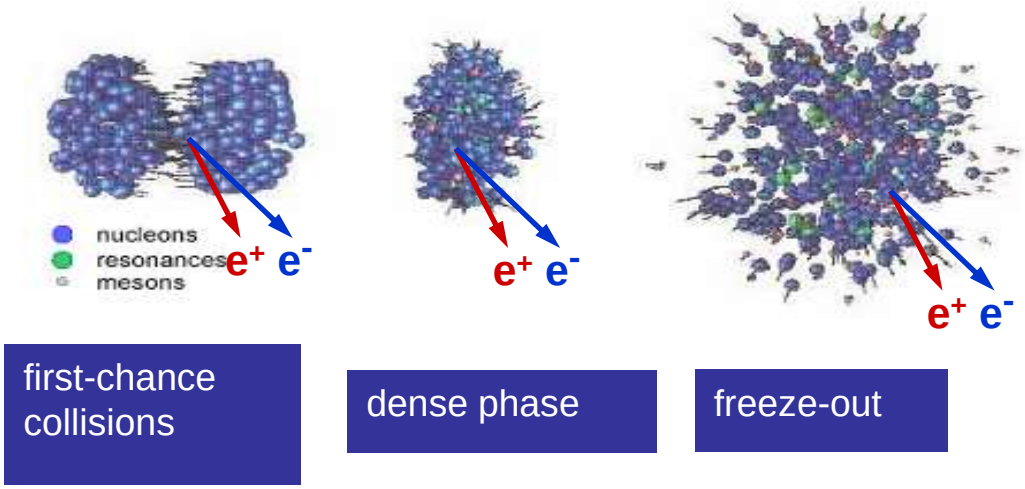
- No strong final interaction
- Reconstruction of in-medium properties possible

But ...

- Very low production probabilities at SIS18 energies
- Low e+e- BR
- Signal integrated over collision history



Collision dynamics



first-chance collisions

dense phase

freeze-out

The measured dilepton signal contains contributions from throughout the collision:

- Direct radiation from the early stage
- Radiation from dense stage
- Radiation from freeze-out stage

→ How to unfold collision dynamics?

SIS18 - Reference measurements for SIS100

Dielectron, pion, baryon resonance production in elementary collisions

p+p (1.25 GeV, 2.2 GeV, 3.5GeV) d+p (1.25 AGeV)

- Constrain contributions to e+e- spectra
- Establish model independent reference spectra for pA and AA collisions

→key reference for SIS100 heavy ion experiments

Hyperon production in p+p (3.5GeV)

- Production mechanism of hyperons: $\Sigma(1385)$, $\Lambda(1405)$

Vector Mesons and Kaon production in p+Nb (3.5GeV)

- Vector Mesons and K^0 modification in cold nuclear matter

→ reference for SIS100 heavy ion experiments

The dielectron excess, strangeness production

C+C (1 AGeV, 2 AGeV), Ar+KCl (1.75 AGeV)

- Origin of the dielectron excess, confirmation of DLS results
- Strangeness production, subthreshold production
- System composition at freeze-out

Dielectron, strangeness production in heavy system: Au+Au (1.25 AGeV)

- Dielectron, strangeness production in heavy system

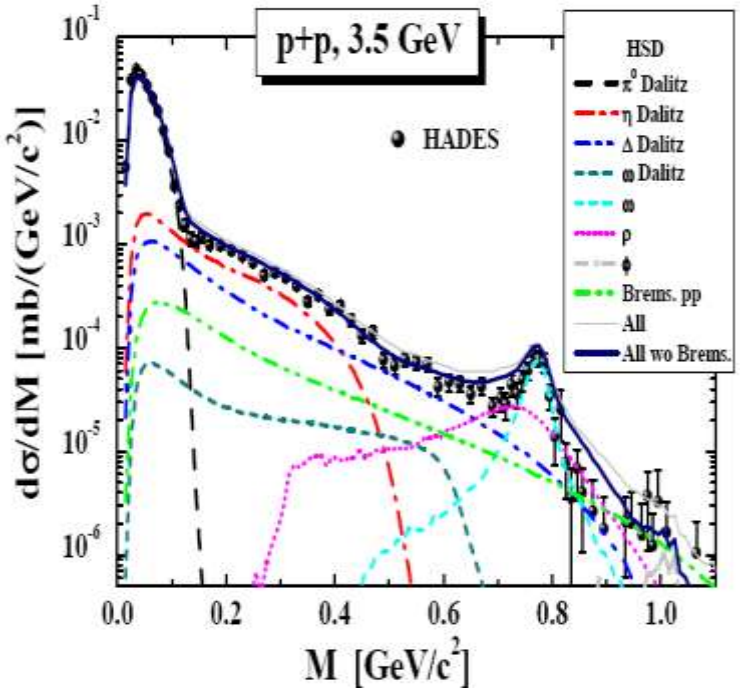
→ benchmark test for HADES at SIS100

Strangeness, hadron and dielectron production in pion induced reactions

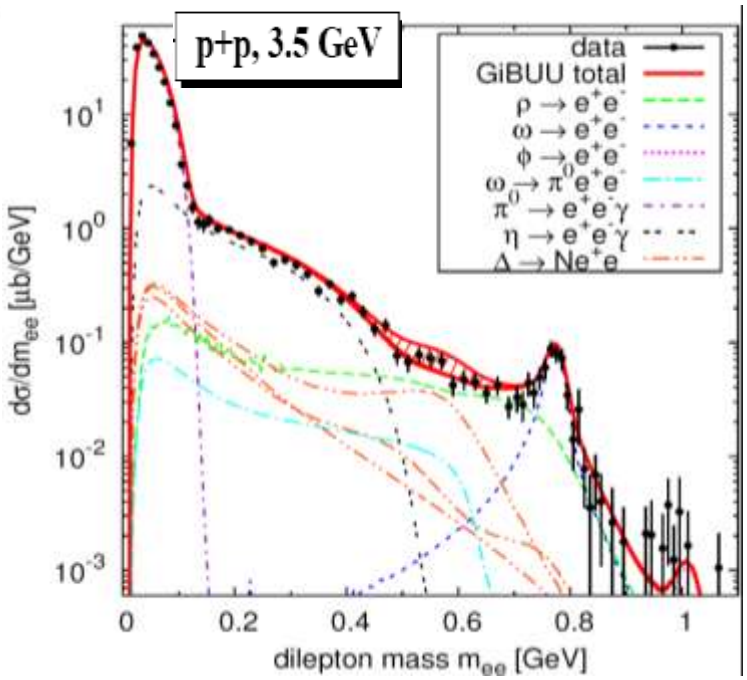
- K-N potencial, phi/K- absorption of mesons in cold nuclear matter
- Coupling of baryonic resonances to off-shell vector mesons: π^- +p→ ne+e- at 0.69 GeV/c

Model predictions for p+p at 3.5 GeV

E. Bratkovskaya et. al., arXiv:1301.0786v1



J.Weil: EPJA48 (2012)111



Uncertainties: - inclusive cross sections π, Δ, η , ω/ρ (fixed now by HADES)
- Δ→pe+e- transition (Dalitz decay), rates, em. TFF
- ρ - spectral function !

HADES, Eur.Phys.J. A48 (2012) 74

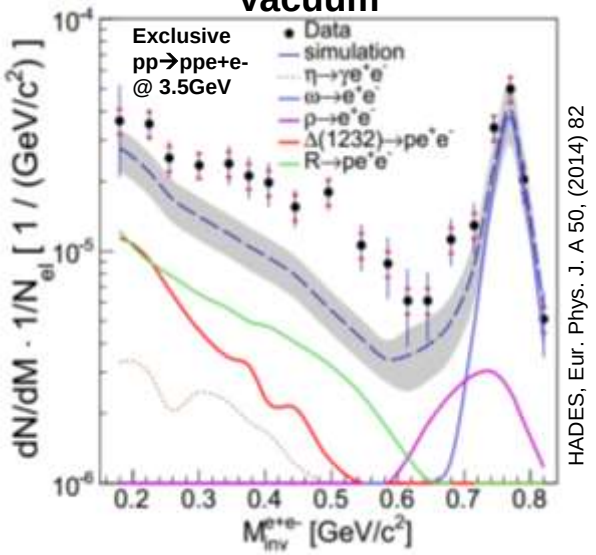
pp @ 3.5 GeV cocktail essential reference for dielectron spectroscopy at SIS100
→ reference for HI experiments !

PDG Entry 2012, 2014, BR(η→e+e-) < 2.5x10^{-6} (90% CL) HADES, Phys.Lett. B715 (2012) 304-309

Reference spectra p+p and p+Nb @3.5GeV

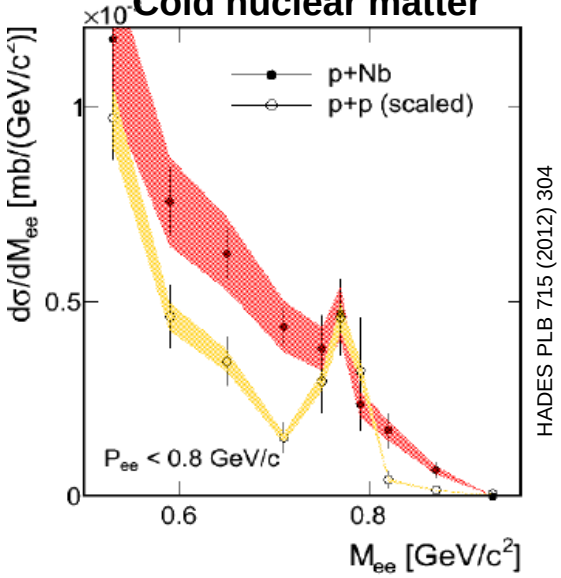
HADES

Vacuum



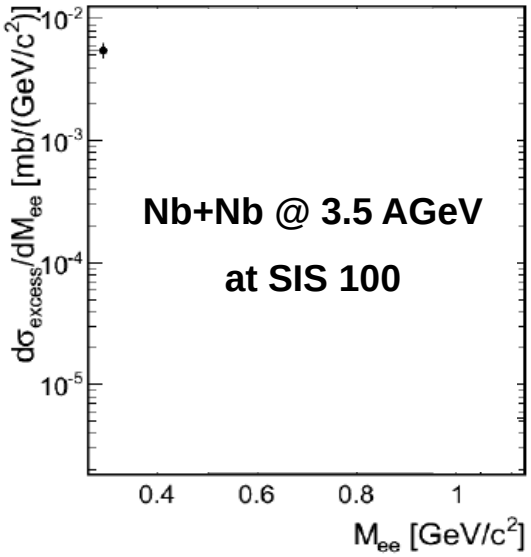
HADES, Eur. Phys. J. A 50, (2014) 82

Cold nuclear matter



HADES PLB 715 (2012) 304

Dense nuclear matter



Visible excess in pp→ppe⁺e⁻ and in p+A below VM pole:

- Secondary reactions :

  $\pi^+N \rightarrow \Delta\,(1720,..)(N^*(1520),..) \rightarrow N\rho \rightarrow Ne+e-$ (i.e. J. Weil GiBUU)

- Or/and in medium ρ modification ?
- R→Ne+e- not known !

Resonance-ρ coupling and pion beams

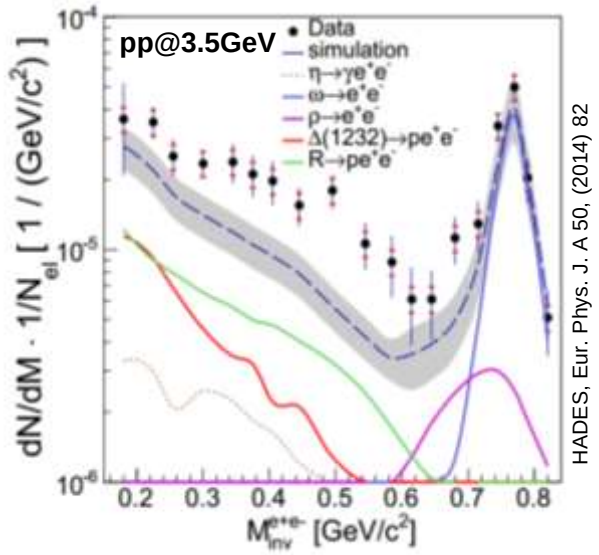
Exclusive pp→ppe+e- spectrum

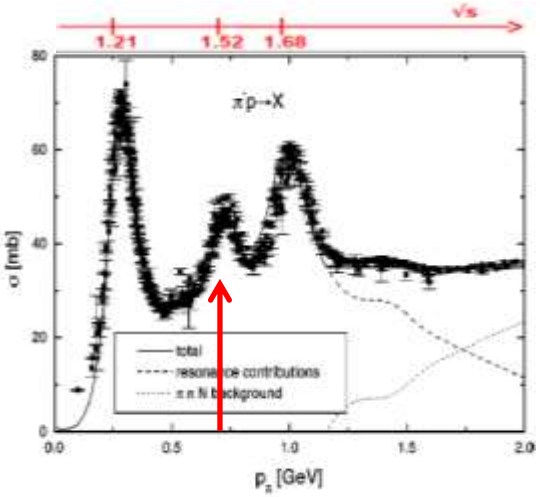
- All resonances R included
- Point-like RNγ* (QED) assumed
- Strong excess below pole mass

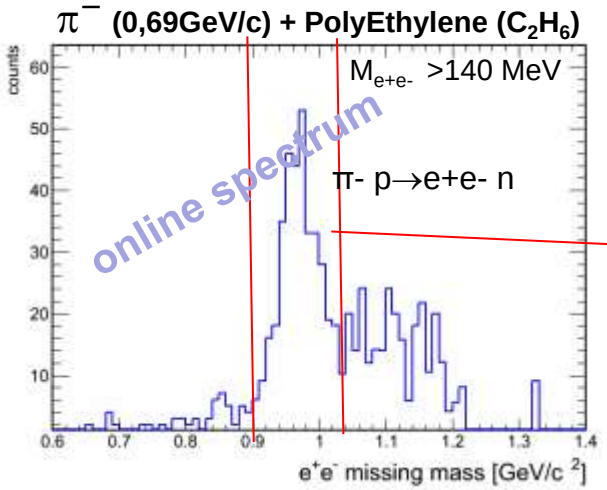
→ **R→Ne+e- needs to be understood !!**

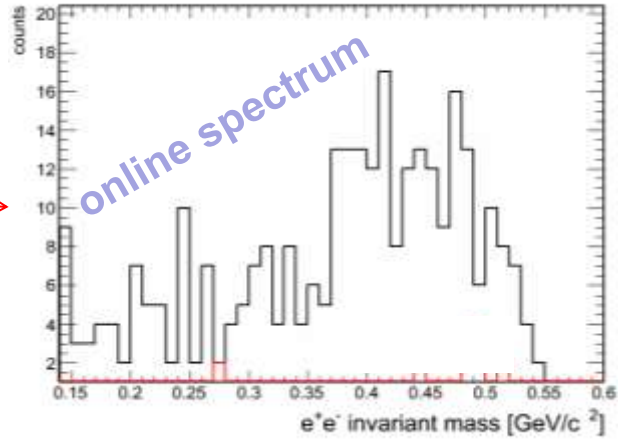
→ **Needed for experiments at FAIR**

Pion induced reactions





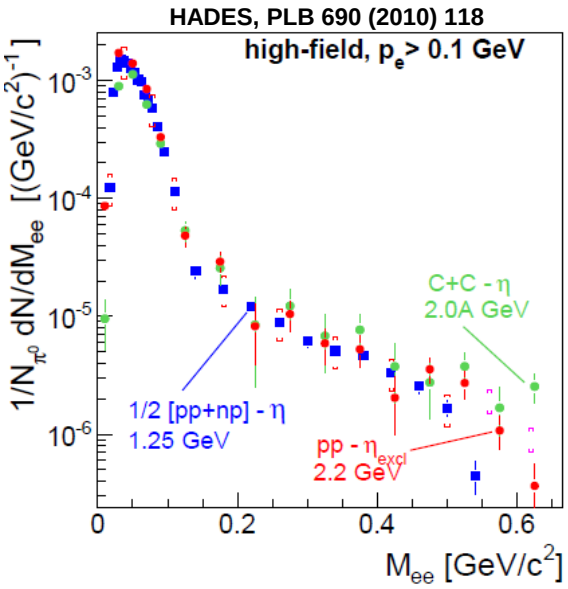


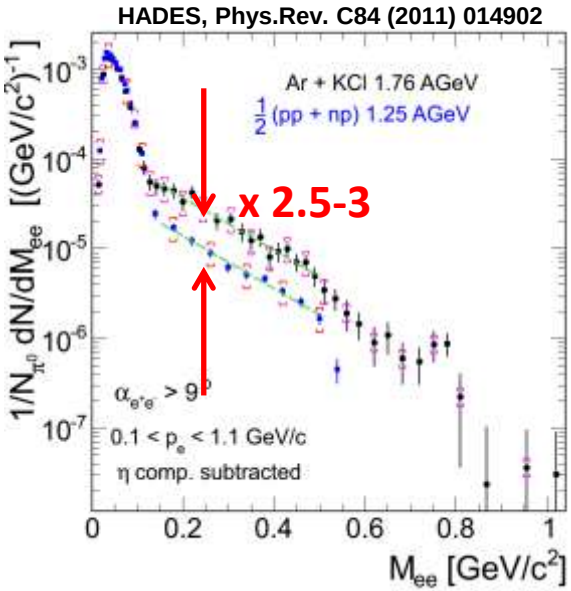


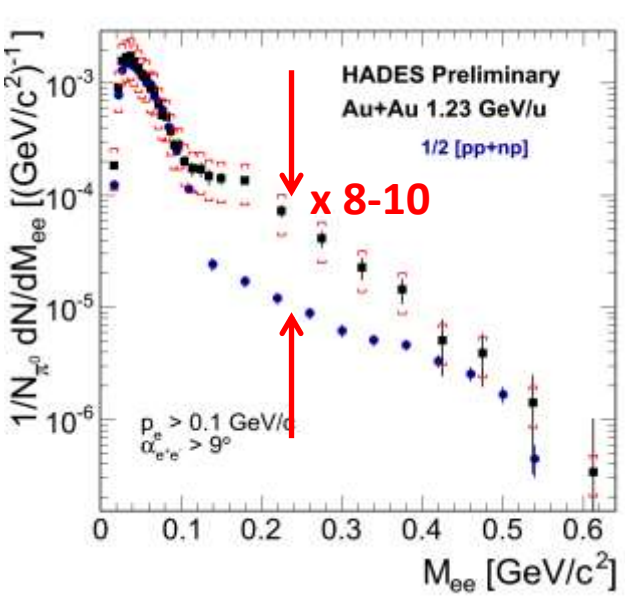
High mass region populated

→ **strong ρ contribution in N* decay**

Dielectron emission in HI collisions







Excess yield scales with system size like $A_{part}^{1.4}$

- Ar+KCl (A_{part} =38), Au+Au (A_{part} =180)
- increase of relative yield -> number of Δ's/N*'s regenerated in fireball

→ SIS100/300 heavy systems at higher energies

Dielectron study at FAIR – terra incognita

No measurement for beam energies of 2-40 A GeV

→ HADES/CBM at SIS100

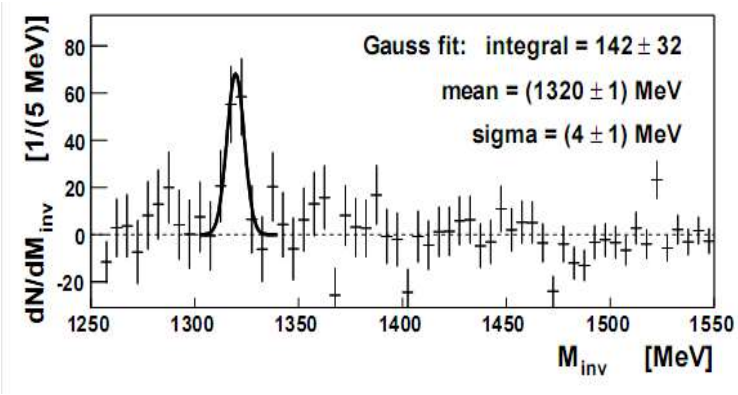
→ CBM at SIS300

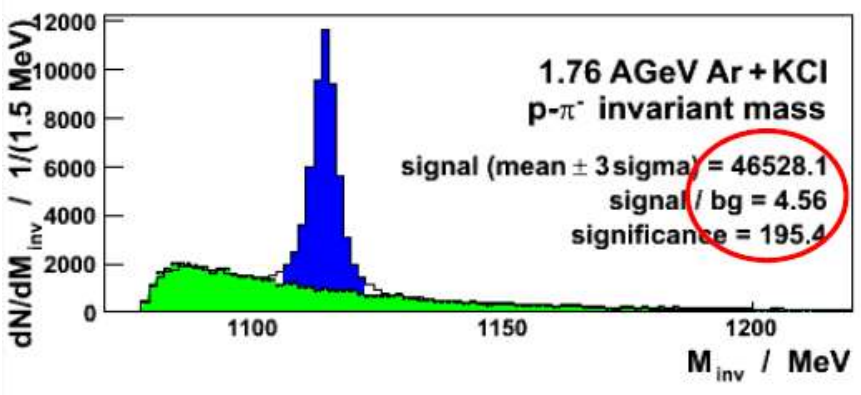
Deep subthreshold production

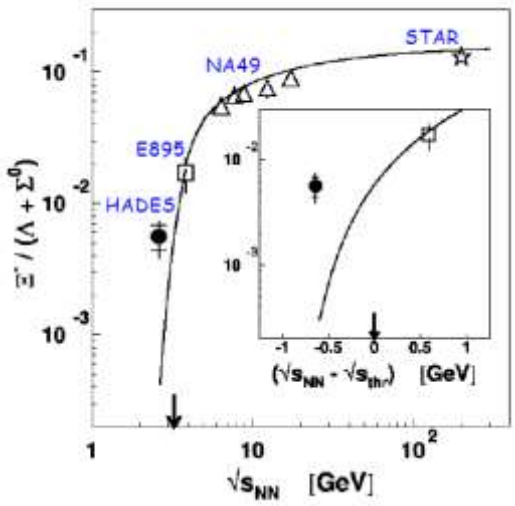
$\Xi^- \to \Lambda\pi^-$ $\Lambda \to p\pi^-$ Ar+KCl @ 1.76 AGeV

HADES

HADES, Phys. Rev. Lett. 103: 132301, 2009







Deep subthreshold production

$\sqrt{s_{NN}} - \sqrt{s_{thr}} = -640\,\mathrm{MeV}$

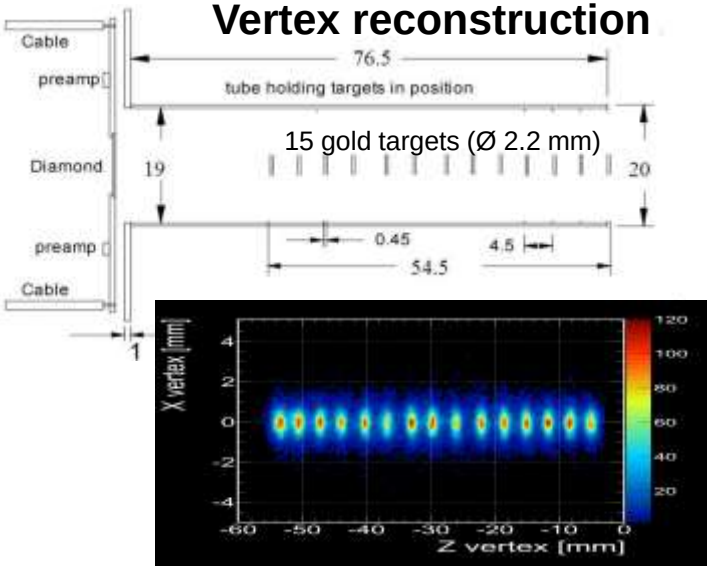
- ✓ Reconstructed signal significantly larger than any model predictions
- ✓ Production mechanism of rare-particles below threshold:
  - → Strangeness exchange? $\bar{K}Y \to \pi\Xi\ (Y = \Lambda, \Sigma)$
  - → Modification of strange hadrons in medium ?
  - → Short range correlated (SRC) pairs effect ?

R.Subedi et al., Science 320, 1476 (2008)

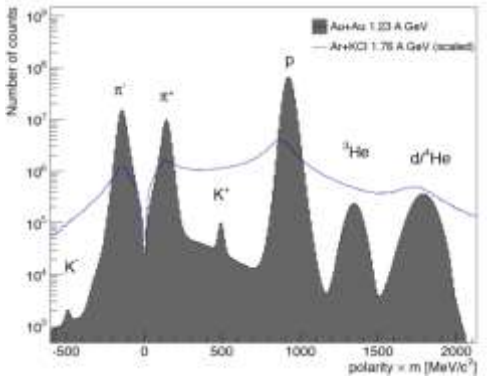
Au+Au @ 1.23 AGeV
benchmark for HADES at SIS100

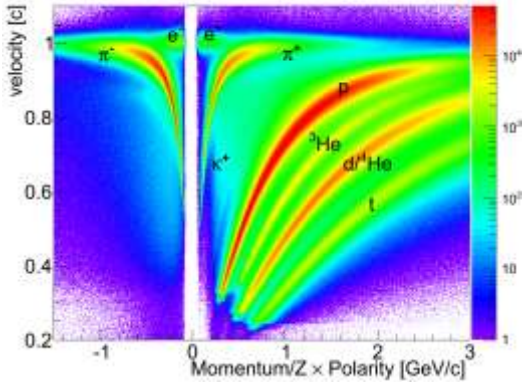
HADES

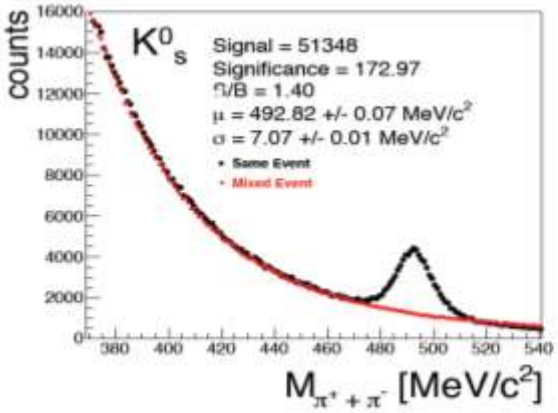
Vertex reconstruction

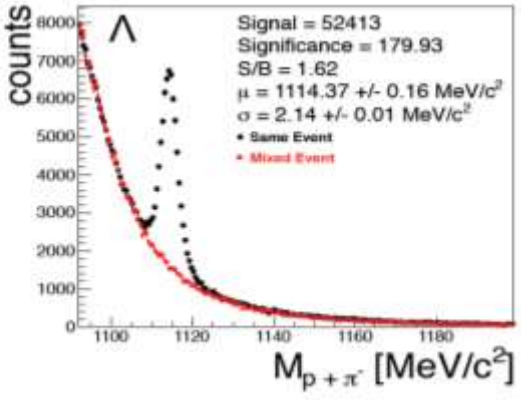


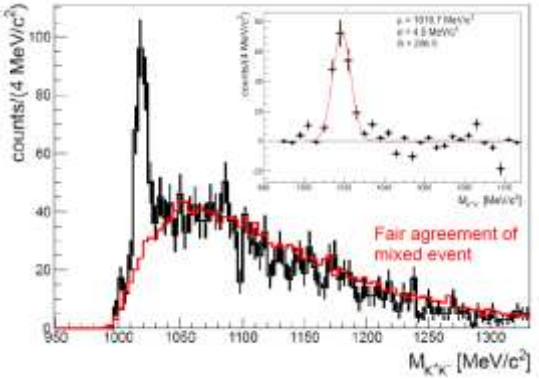
$$NN \rightarrow NK^+\Lambda \quad (E_{thr} = 1.58 GeV)$$
$$NN \rightarrow NNK^+K^- \quad (E_{thr} = 2.49 GeV)$$
$$NN \rightarrow NN\varphi \quad (E_{thr} = 2.59 GeV)$$







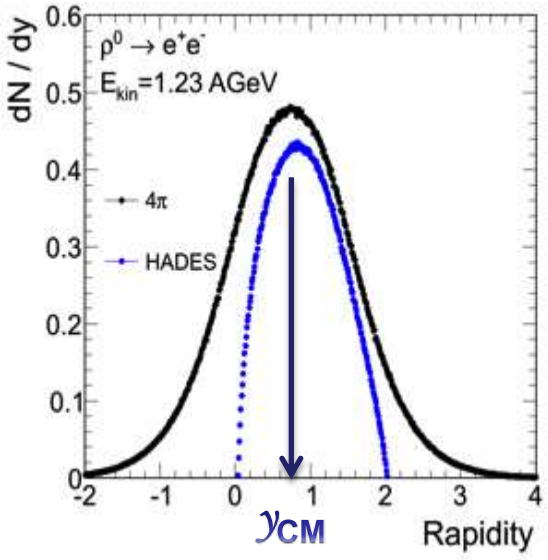


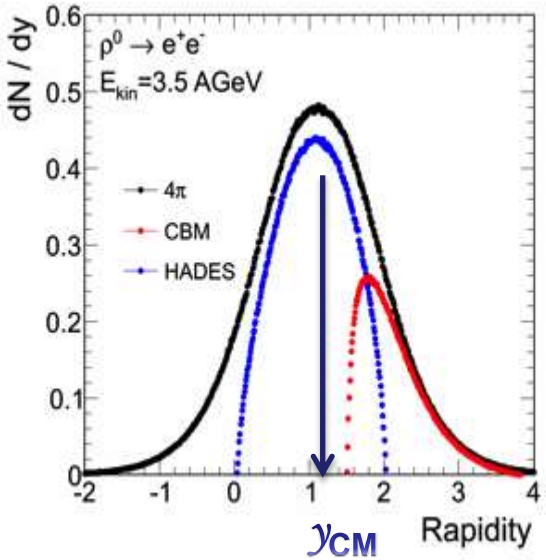


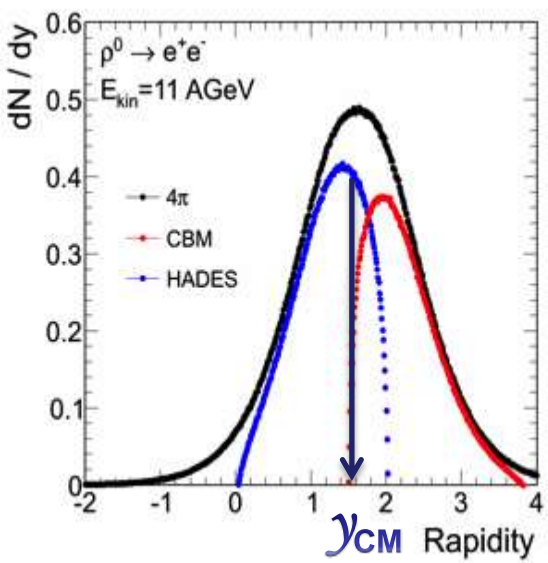
K^0_s, K^-, Λ, φ - First measurement at such low beam energy !

Beyond Au+Au @ 1.23 AGeV

Phase space coverage for e^+e^- from ρ decays for HADES and CBM







E_{beam} = 1 GeV/u

- Acceptance for di-electron pairs ≈ 35%
- perfect mid-rapidity coverage

E_{beam} = 3.5 GeV/u

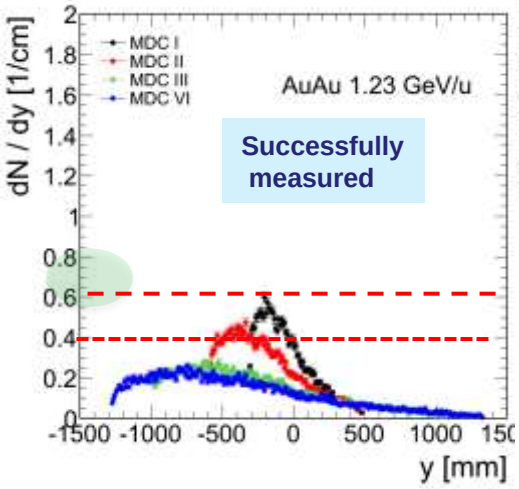
-Acc ≈ 20%

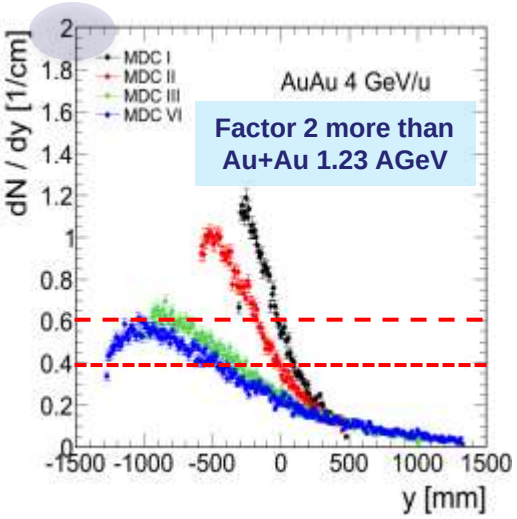
-Shift towards backward rapidity

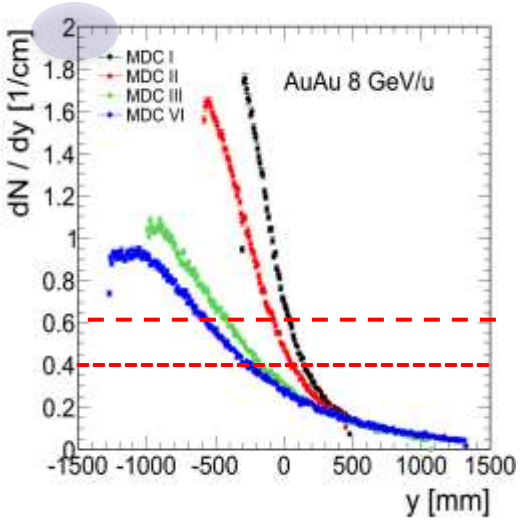
E_{beam} = 11 GeV/u

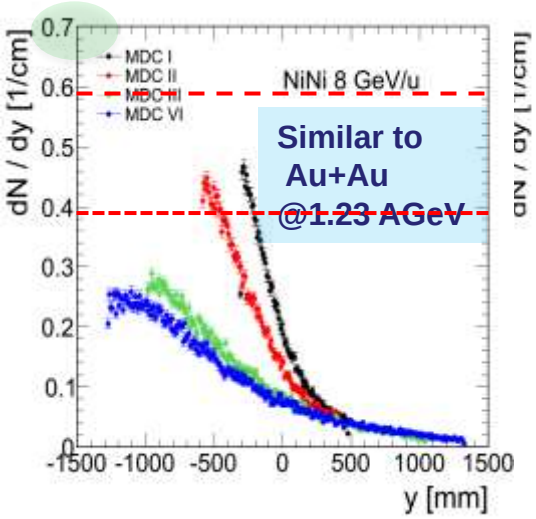
→ Acc ≈ 20%

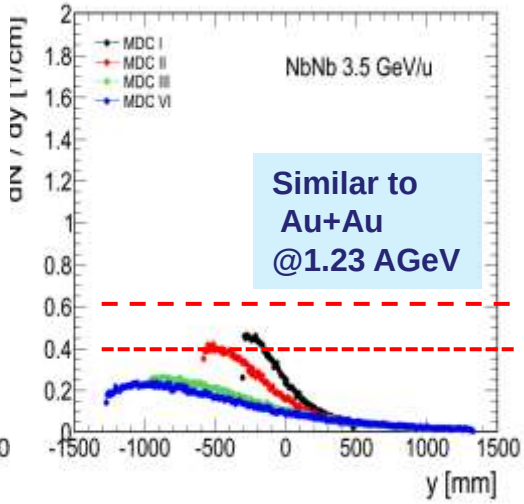
Beyond Au+Au @ 1.23 AGeV - challenges











- - - - - 36 % cell occupancy
- - - - - - - - 24 % cell occupancy

Main limitation:
Fake tracks at high occupancy !

→ HADES @ SIS100 can handle systems comparable to Au+ Au @ 1.25 AGeV

HADES electromagnetic calorimeter

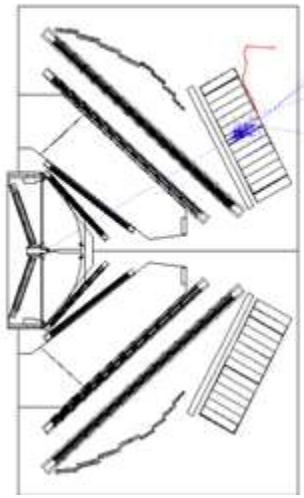
For pair excess determination a precise knowledge of the hadronic cocktail is essential (particle yields at chemical freeze-out)

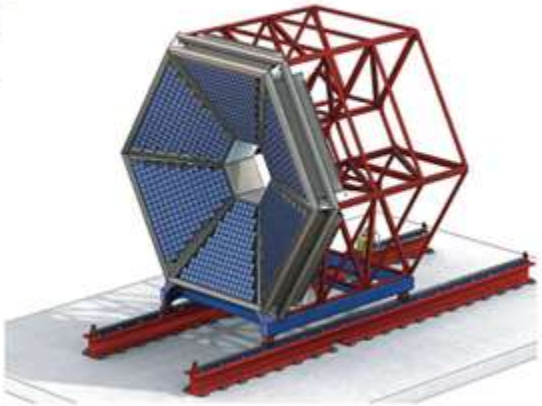
- ✓ At 2-40 AGeV mainly dominated by η-Dalitz
- ✓ Normalization to π^0 (at SIS18 – TAPS data)

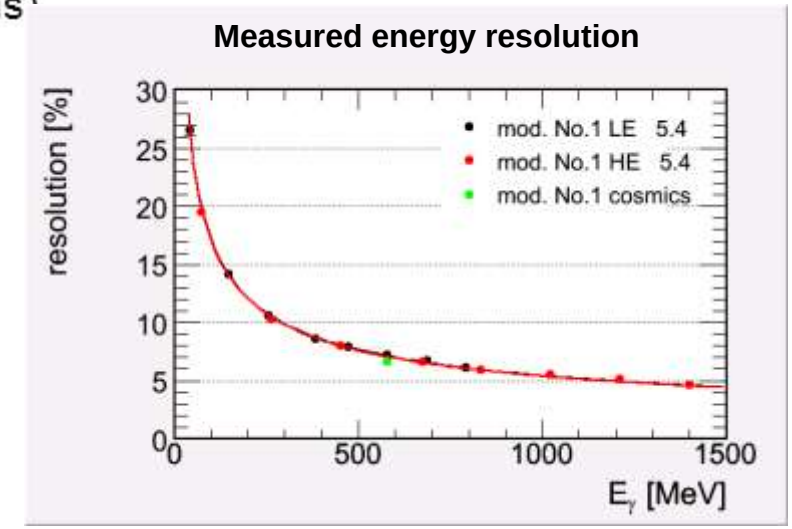
→ Calorimeter for HADES

- → π^0, η measurement
- → improved pion suppression
- → direct photon measurement
- → neutron detection

✓ substitute for Pre-Shower ($18^o<\Theta<45^o$, 8 m^2;18 tons)

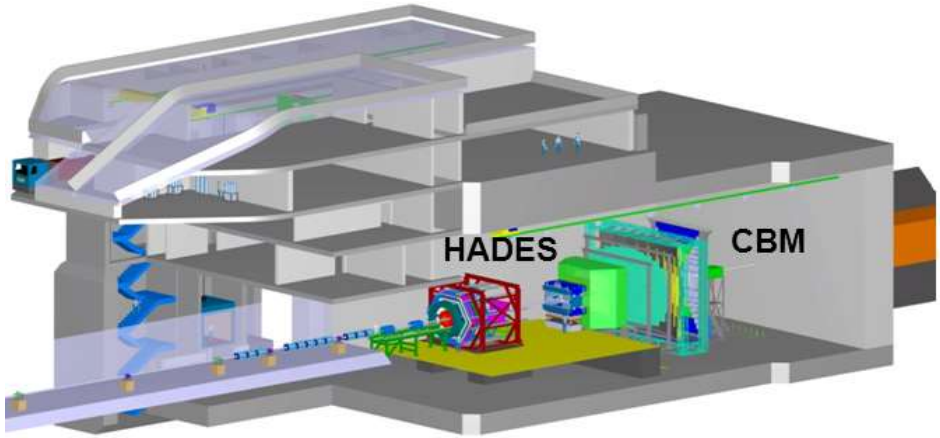






Summary

- ✓ Collected reference data for HADES/CBM at FAIR
- ✓ Excellent detection capabilities demonstrated at Au+Au @ 1.23 AGeV
- ✓ Terra incognita up to 40 AGeV – waiting for experiments (HADES/CBM)
- ✓ Pion induced reaction – very powerful tool to answer most of the open questions
- ✓ Additional detection potential by ECAL for HADES – in preparation
- ✓ Broad program for HADES at SIS100
  - → Completion of dielectron excitation with Nb+Nb @ 3.5 AGeV
  - → Light systems at higher energies Ni+Ni @ 8 AGeV
  - → Multistrangness production in 3-5 AGeV energy region
  - → Understanding of resonance excitation and dilepton decay mechanism (pion, proton beams)



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156 members

Thank you

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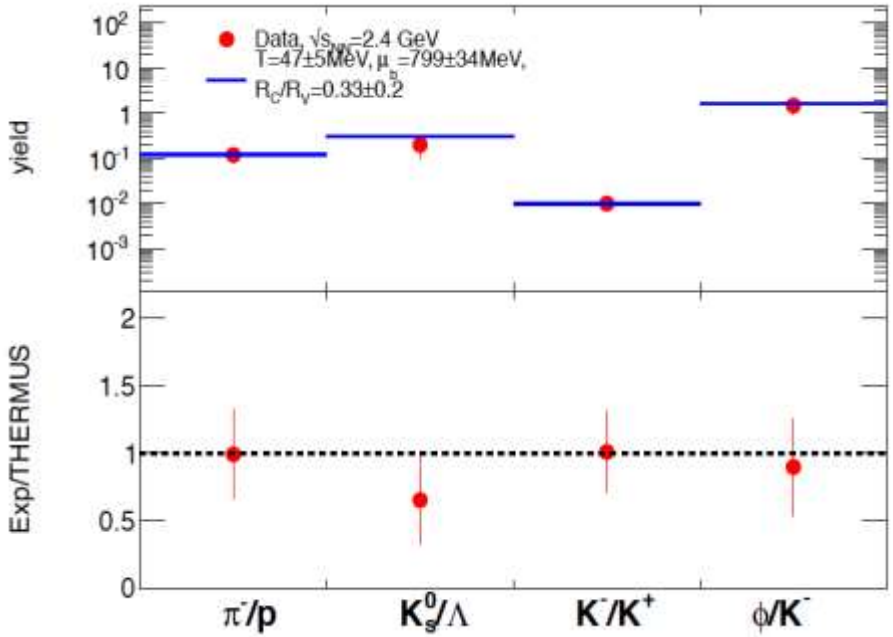
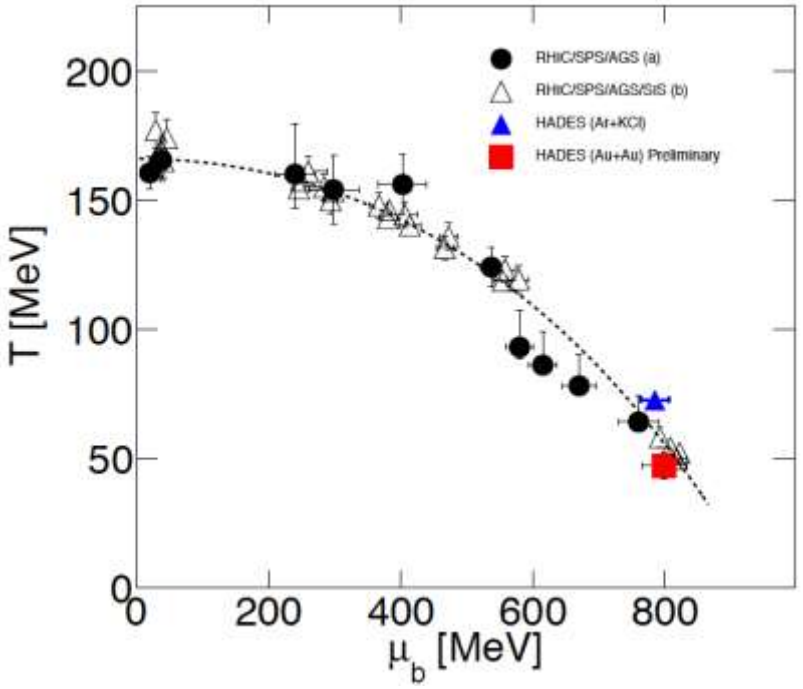
Freezeout in Au+Au @ 1.23 AGeV





→ **Statistical model works reasonable well at low energies and medium-sized systems**

THERMUS fit: J.Cleymans, J.Phys.G31(2005)S1069

Ar+KCl @ 1.76 AGeV: HADES, Phys.Rev.C80:025209,2009

Au+Au @ 1.23 AGeV: HADES preliminary